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A PRELIMINARY ACCOUNT OF THE DEVELOPMENT OF THE APYRENE SPERMATOZOA IN *STROMBUS* AND OF THE NURSE-CELLS IN *LITTORINA*

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The dimorphic spermatozoa in *Strombus* were first described by Brock in 1887 in the case of *S. Lentiginosus*. While accurate enough in general, his account is lacking in certain interesting details and he also made no attempt to trace the developmental stages of either kind of spermatozoa Both his description and his figures, however, are sufficient to show how marked and striking is the dimorphism existing here and it is surprising that this has not been made the subject of further investigation by more recent workers.

My attention was attracted to *Strombus* in May, 1911, while at the temporary laboratory established by The Carnegie Institution of Washington at Port Royal, Jamaica, W. I. There I had the opportunity of observing the living spermatozoa and also of securing a lot of material for further study. The species studied was *S. bituberculatus*. My thanks are due to Dr. H. A. Pilsbry of The Academy of Natural Sciences of Philadelphia, who kindly identified it for me.

Adopting the terminology suggested by Waldeyer and used first by Meves ('03), the two kinds of spermatozoa found in *Strombus* are the eupyrene, *i. e.*, those that function in the ordinary way, and the apyrene whose function is unknown and in whose adult structure there is no active nuclear material. The eupyrene spermatozoa do not present any striking differences from those found in other forms which have the same sexual dimorphism, *Paludina* for example, but they lack the tenuous

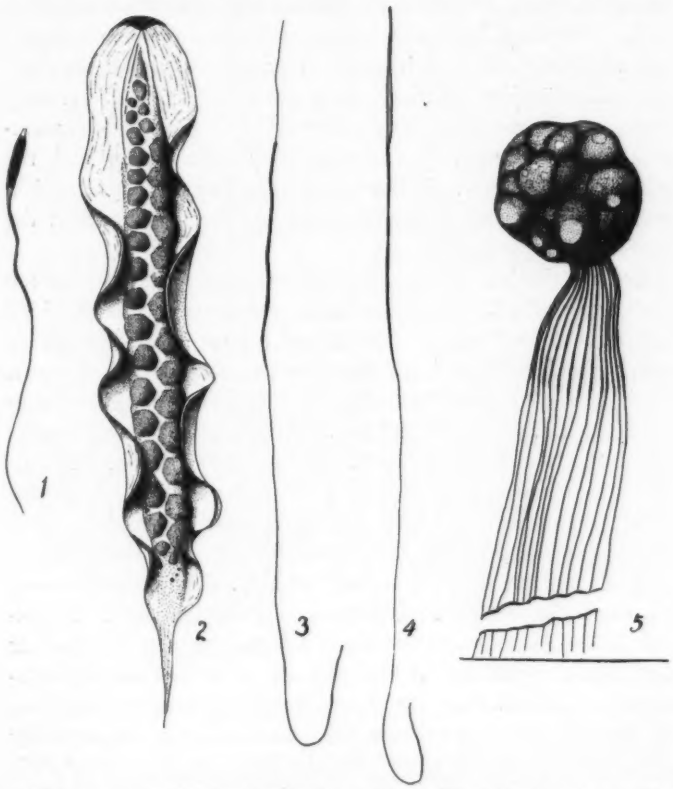
perforatorium and the very long tail-piece of the spermatozoa found in forms like *Littorina* and *Fasciolaria* (Fig. 3). The apyrene spermatozoa, on the other hand, bear very little resemblance to those described in other forms and to the eupyrene spermatozoa they bear absolutely none at all. They are very much larger than the latter and are outnumbered by them, according to Brock's estimate, about 1 to 500; the correct numerical relation existing between them in *S. bituberculatus* has not been ascertained but it is probably the same as in *S. lentiginosus*. In length the apyrene spermatozoa average somewhat over 90 micra.

The adult apyrene spermatozoön is composed of a central spindle-shaped cell body, which is long and narrow and slightly flattened dorso-ventrally, and two undulating membranes which pass down either side of the cell-body (Fig. 2). At the anterior end of the spermatozoön the membranes round out sharply to their maximum width while posteriorly they narrow more gradually and finally end in a short sharply pointed tail-piece. The interior of the cell-body is filled with a number of large polygonal bodies composed of an albumen, probably a nutritive material. These bodies are more or less regular in shape and position but they decrease in size at either end of the cell.

The living spermatozoa, as they leave the sperm-ducts, do not show any violent movements; at first long slow contraction waves pass alternately down the two membranes in a postero-anterior direction, propelling the spermatozoön in the opposite direction, that is, the posterior end is directed forward.[1] Occasionally a spermatozoön is seen moving with its anterior end directed forward. The movement of the spermatozoön is com-

[1] In *Paludina* that end of the spermatozoön which contains the remains of the nucleus, *i. e.*, the head, has been designated as the anterior end and this is the end which is directed forward in movement; it is also the end toward which the axial fibers have grown. In *Strombus*, on the other hand, there is no nuclear head in the spermatozoön and therefore, following the precedent established above, I have designated as anterior that end toward which the axial fibers have grown. It happens as a rule that in movement this end is directed backward. It was thought better to orient the spermatozoön morphologically rather than by the direction of movement. To be correct, the orientation should be reversed in both cases as the end of the eupyrene spermatozoön toward which the axial fiber has grown is the posterior one.

paratively slow and is not long continued as it soon attaches itself by means of its tail-piece to the glass slide or other object upon which it is being observed. As soon as this occurs the contraction waves pass down both the membranes simultaneously



FIGS. 1 to 5. Initial magnification of 1,850 diameters, reduced one third. Fig. 1, eupyrene spermatozoön of *Strombus bituberculatus*. Fig. 2, apyrene spermatozoön of the same form. Fig. 3, spermatozoön of *Littorina nebulosa* showing the long, thin perforatorium. Fig. 4, spermatozoön of *L. angulifera* showing the perforatorium swollen after being in sea-water for some time. Fig. 5, nurse-cell of *L. nebulosa* with attached spermatozoa; drawing made from a living cell.

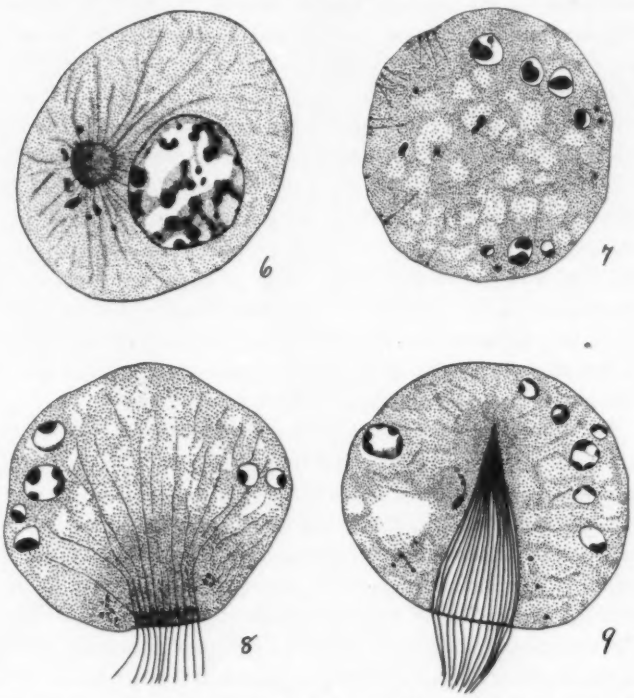
and they become much shorter and faster. With the spermatozoön attached in this way, the membranes may continue to be active for an hour or two. It very frequently happens, however,

that the tail-piece breaks off and the spermatozoön swims away with a much more rapid movement than it had at first. When the tail-piece begins to break off it can be seen to be composed of a number of fused flagella; sometimes as the spermatozoön moves away one or more of the flagella may be seen still adhering to it. This explains the statement of Brock to the effect that a tuft of flagella, which is invisible at first, is to be seen after the spermatozoön has been swimming about for a while. It very frequently happens that long before the undulations of the membranes have ceased, the spermatozoön flattens out and the albuminous bodies break down, leaving in their place a brownish, semi-fluid substance in which, however, may still be seen the outlines of those bodies.

As in *Paludina*, the apyrene spermatocytes of *Strombus* are easily recognized. They are large pear-shaped cells provided with a nucleus of regular pattern and a large centrosome about which may be seen an inner clear court and an outer dark court. Until a very late stage in their growth period they retain a connection with the cyst-wall of the testis by means of a short stalk; later they lose this attachment and become spherical. By this time the chromatin has begun to form in lumps beneath the nuclear membrane and from a large number of centrioles lying at the periphery of the centrosome strong radiations may be seen to pass out in all directions (Fig. 6). In the outer court, but away from the nucleus, lies a mass of mitochondria. A division of the nucleus and cell never follows; instead, the nuclear wall breaks down and the centrosome with its radiations disappears. A little later the chromatic masses are seen scattered through the cell while the centrioles have moved to the periphery of one half of the cell where they are easily recognized by their radiations (Fig. 7). The cell now begins to develop directly into the spermatozoön.

The chromatin, as such, takes no further active part in the development of the spermatozoön; the fragments very soon begin to become vesiculated and to degenerate. The centrioles mass together at a point just beneath the cell membrane where they divide (Fig. 8). One half of the number of daughter or secondary centrioles remain attached to the cell-membrane and

from them grow out flagella which ultimately fuse to form the tail-piece. The others move across the cell forming a bundle of axial fibers. At its base the bundle is round but it becomes more and more flatly oval as the fibers move across the cell (Fig. 9).



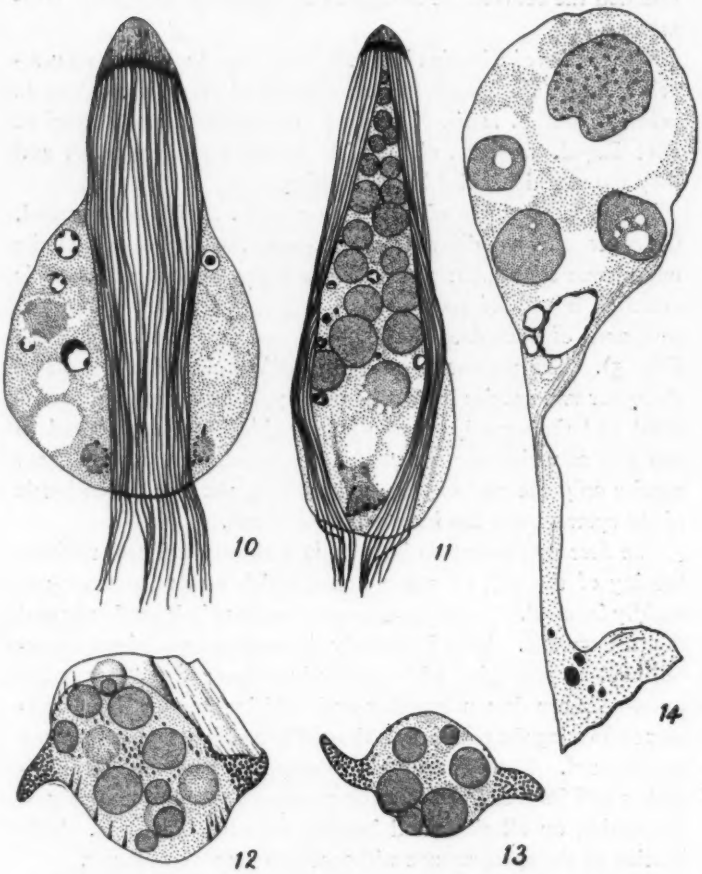
FIGS. 6 to 9. Initial magnification of 3,450 diameters, reduced one third. Various stages in the early development of the apyrene spermatozoa of *Strombus bituberculatus*. Fig. 6 is a spermatocytic stage just before the breaking down of the nucleus and the disappearance of the centrosome. Fig. 7 is a stage following the breaking down of the nucleus; the centrioles figured represent only a portion of the total number in the cell. Fig. 8 shows the beginning of the bundle of axial fibers. Fig. 9 shows the fibers grown partly across the cell; the view is taken at an angle of 90 degrees from that of Figs. 8 and 10.

The mitochondria may be seen to form the inner margin of a ring of differentiated cytoplasm which surrounds the base of the bundle. They persist here until the spermatozoön has reached its adult form (Figs. 8 and 10).

When the bundle of axial fibers, by its growth, has increased the length of the cell by about one third, it splits and the halves begin to move to either side of the cell (Figs. 10 and 11). This movement is caused by a twisting of the secondary bundles, due probably to the unequal growth of the fibers. This process continues until they push out the cell membrane on either side to form the undulating membranes (Figs. 12 and 13). Fig. 12 is an oblique section through the middle of a spermatozoön which has not quite matured; later the membranes become flatter and wider as shown in Fig. 13, which is a more anterior section of a still older spermatozoön. As is indicated in Fig. 12, the continued growth of the fibers without a compensating increase in the length of the cell causes several even folds to occur throughout the length of the membranes. Some of the axial fibers do not participate in the formation of the membrane. As the bundles begin to evaginate the cell membrane, a few of the fibers begin to migrate and finally come to lie longitudinally across the cell and just beneath its membrane (Figs. 12 and 13).

The albuminous bodies are formed in the same way as Kuschakewitsch ('11) has briefly described in *Vermetus gigas*. Large vacuoles appear in the cytoplasm, first in the anterior portion of the cell, and these gradually become filled with an albuminous substance. When such a vacuole has been almost filled but before a membrane is formed, narrow strands may be seen connecting the albumen with the surrounding cytoplasm (Fig. 11). The cytoplasm which is not displaced by the formation of these bodies becomes fibrillar, the greater part of it forming a core down the center of the spermatozoön (Figs. 12 and 13).

As the spermatozoön develops, the vesiculated nuclear fragments which were scattered throughout the cell continue to degenerate. They gradually become more condensed and darkly staining and undergo further fragmentation. They may dissolve *in situ*, but they may also go to form the many small granules that lie in amongst the fibers composing the undulating membranes (Fig. 13). These granules are probably mitochondria and while at present it cannot be definitely asserted that they are thus of a direct nuclear origin, there is considerable evidence in favor of this view. The mitochondria which originally sur-



FIGS. 10 to 14. Initial magnification of 3,450 diameters, reduced one third. Figs. 10 to 13, various stages in the later development of the apyrene spermatozoa of *Strombus bituberculatus*. Fig. 10, bundle of axial fibers beginning to split; a few albuminous bodies, not figured, have been formed in the anterior portion of the cell. Fig. 11 shows the completed splitting of the bundle of axial fibers; the cell is not cut through its greatest breadth. Figs. 12 and 13 are sections through two nearly adult spermatozoa. Fig. 14 is a nurse-cell of *Littorina nebulosa* still attached to the wall of the testis; the stalk was about to be severed just below the degenerating nucleus.

rounded the centrosome remain at the posterior end of the spermatozoön.

The species of *Littorina* in which have been found a free nurse-cell to which the spermatozoa are attached are *L. angulifera*, *L. nebulosa* and *L. rudis*. The first two species were studied at Port Royal, Jamaica, along with *Strombus bituberculatus*, and they too were identified by Dr. Pilsbry.

If the sperm-ducts of *L. nebulosa* or *L. rudis* are ruptured, the contents, when diluted with sea-water, will appear under the microscope as a great number of spheres to each of which is attached a tuft of spermatozoa. The spheres are nurse-cells composed of vacuolated yolk bodies and a degenerate nucleus (Fig. 5). The nurse-cells of *L. angulifera* differ from those of the other two species in that here the yolk bodies are not vacuolated and they partly enclose a long thick cytoplasmic rod to one end of which are attached the spermatozoa. In all three species only the perforatoria and possibly the tips of the heads of the spermatozoa are inserted into the cell.

The first movement to be seen is a rhythmical and uniform beating of the tuft of spermatozoa which sends the nurse-cell rapidly forward. Later the spermatozoa beat independently and the tuft spreads. Very frequently the spermatozoa of one nurse-cell become entangled with those of another; in that event the nurse-cells are drawn together and held by an agglutinous substance forming the pabulum in the cell into which the spermatozoa are inserted. In this way a great many nurse-cells are drawn together and from such a mass the spermatozoa may later be seen protruding on all sides and beating regularly like cilia. This beating of the spermatozoa will continue for several hours.

In case a nurse-cell has not become entangled with others, the spermatozoa soon free themselves; their heads become further and further separated from the nurse-cell until the attachment is completely lost. A sperm thus freed is seen to have a long, thin perforatorium behind which is the head; the latter passes almost imperceptibly into a very long tail (Fig. 3). After the spermatozoön has been swimming about in the water for a time the perforatorium becomes swollen; this is what has usually been figured as the sperm head. The whole process can be seen to better advantage in *Fasciolaria*.

The nurse-cells develop from large cells which are attached to the walls of the testis by a long stalk. These cells closely resemble the apyrene spermatocytes of *Strombus* except that they lack the pronounced centrosome of the latter. The only indication of such a structure in the case of *L. nebulosa* is a series of fibers running up one side of the cell. This later disappears and probably forms the portion of the cell to which the spermatozoa are attached (Fig. 14). In *L. angulifera*, in the early stages of the nurse-cell, there is a darkly staining body lying in the cytoplasm which grows to form the rod spoken of above; this also may be of a centrosomal origin. The formation of the yolk bodies is much the same as that of the bodies described in *Strombus*. They differ, however, in that here they reach a much larger size and then fragment into two or more parts. Coincident with this cytoplasmic differentiation the nucleus undergoes partial degeneration; it simply becomes more and more vacuolated but never completely disappears.

Before the nurse-cell has reached its full development it loses its connection with the wall and moves into the lumen of the testis. Here the spermatozoa become attached. The nurse-cells function as such in the sperm-ducts. Sections of *L. rudis*, made from a specimen killed in February, showed the nurse-cells in the sperm-ducts to be in a more or less depleted condition.

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CERTAIN MEANS BY WHICH STARFISH EGGS NATURALLY RESISTANT TO FERTILIZATION MAY BE RENDERED NORMAL AND THE PHYSIOLOGICAL CONDITIONS OF THIS ACTION.

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Last summer at Woods Hole, while investigating the influence of ether and other anæsthetics in protecting the unfertilized eggs of starfish against the cytolytic action of pure isotonic sodium chloride solution,[1] I observed that toward the end of the breeding season the eggs often proved abnormally resistant to this solution, withstanding in some instances exposure of more than three hours to 0.55*m* NaCl without losing the power of development on fertilization; in normal eggs this solution typically causes complete cytolysis and coagulation of the protoplasm in two hours or less. Other characteristic abnormalities of behavior were found to be associated with this abnormal resistance to salt solutions. Usually a large proportion of such eggs failed to undergo maturation in sea-water, and of those which matured only a small proportion developed to a free swimming stage on fertilization, and the resulting larvæ were largely abnormal. Also the mature eggs, if left unfertilized in sea-water, frequently failed to die and break down within the usual time, but remained clear and apparently normal in appearance for an unusually prolonged period. It is well known that unfertilized mature starfish eggs undergo spontaneously a characteristic cytolytic alteration, accompanied by a darkening or coagulation of the protoplasm, which is typically complete within twelve to fifteen hours after deposition;[2] in contrast to this behavior a considerable proportion of the eggs under consideration often remained clear and uncoagulated in sea-water for twenty-four and in some cases for forty-eight hours. These several peculiarities, (1) failure of

[1] *American Journal of Physiology*, 1912, Vol. 30, p. 1.

[2] Cf. J. Loeb, *Archiv für die gesammte Physiologie*, 1902, Vol. 93, p. 59.

maturation in a large proportion of eggs, (2) failure of those eggs which did maturate to develop after fertilization, (3) marked delay in the typical post-maturational cytolysis of unfertilized eggs, and (4) unusual resistance to the cytolytic action of salt solutions were found in more or less constant association with one another in numerous lots of eggs. All of these peculiarities are evidence of a certain inertia or resistance to change in the egg-system; such eggs fail to react, or react slowly and imperfectly to conditions which call forth a definite and regular response in normal eggs. The fact of their concurrence, as well as their general nature, suggests that some single structural or metabolic abnormality, whose general effect is to lower reaction-velocities in the egg-system, is responsible for all of these peculiarities of behavior.

The further incidental observation was made in several instances that such eggs after treatment for two or three hours with sodium chloride solution containing a little ether or chloral hydrate recovered to a considerable degree the power of developing to a normal larval stage on fertilization; *i. e.*, eggs so treated yielded more numerous and more active larvæ than the untreated eggs of the same lot, fertilized at the same time. Pure sodium chloride solution showed a similar though less marked action. The surprising result thus appeared that treatment with solutions which are markedly injurious to normal eggs may bring a certain proportion of these abnormal or "over-ripe" eggs into a condition—as regards power of development on fertilization—closely approaching the normal.

The following record will illustrate the above-described conditions in detail.

June 29, 1911. The eggs were removed from a considerable number of starfish at 10.00 A.M. A large proportion of these mixed eggs remained permanently immature in sea-water (with intact germinal vesicles), but about half underwent apparently normal maturation. On fertilization (at 3:30 P.M.) very few of the eggs—a fraction of one per cent.—formed blastulæ, most died in early cleavage stages, but many failed to cleave or even to form fertilization-membranes. The unfertilized mature eggs after twenty-four hours in sea-water remained for the most part clear and translucent with no sign of coagulation; a good many, however, showed apparently normal coagulation, while others showed an intermediate condition. After forty-eight hours many unfertilized mature eggs were still uncoagulated.

About two hours after removal from the animals the unfertilized eggs were

placed in the following solutions: (1) pure 0.55*m* NaCl, and (2–10) 0.55*m* NaCl containing anæsthetics as follows: (2–4) ether, 0.6, 0.45, and 0.3 volumes per cent., (5–7) chloral hydrate, 0.6, 0.4 and 0.2 per cent., (8–9) chloroform, one sixth and one tenth saturated, and (10) ethyl alcohol, 5 volumes per cent. After three hours and fifteen minutes in these solutions the eggs were transferred to normal sea-water and washed free of the anæsthetics by two changes of sea-water; spermatozoa were then added. At the same time spermatozoa were added to the untreated eggs which had remained in sea-water. The results were as follows: of the control eggs, fertilized in sea-water without treatment, almost all died before reaching the blastula stage; only a few feeble blastulæ (a fraction of 1 per cent.) were found on careful search; many eggs failed to cleave or even to form membranes. The eggs exposed to pure 0.55*m* NaCl also formed few blastulæ, but these were relatively somewhat more numerous as well as more active than in the control; the eggs treated with 0.55*m* NaCl containing 0.45 and 0.3 vol. per cent. ether, especially the latter, showed a more decided improvement over the control, though the proportion of blastulæ was still small. The eggs from the other solutions showed no improvement.

A similar result was observed in a second series of experiments with eggs which showed similar peculiarities. Eggs treated for three hours with 0.55*m* NaCl containing 0.3 vol. per cent. ether gave about 5 per cent. of blastulæ, while of the control untreated eggs less than one per cent. reached this stage. Eggs similarly treated with solutions containing a higher proportion of ether (0.75, 0.6, and 0.45 vol. per cent.) showed no improvement over the control. In another series eggs exposed for 3 h. 45 m. to 0.55*m* NaCl containing 0.1 per cent. chloral hydrate gave considerably more blastulæ than the control eggs.

It is to be noted that the improvement in the developmental power of these abnormal or resistant eggs was produced only by the pure salt solution or by solutions with a *low* concentration of anæsthetic. The concentration of ether most favorable for retarding the cytolytic action of 0.55*m* NaCl is considerably higher—from 0.5 to 0.6 vol. per cent.[1] The present effect, however, is not due to a simple prevention of cytolysis; the improvement over eggs left in sea-water, none of which undergo cytolysis within the time of exposure, cannot thus be explained. The effect is different from a simply protective action; and since it seemed to be favored by weak solutions of ether, the experiment was tried of exposing a batch of similarly abnormal eggs to sea-water containing 0.3 vol. per cent. ether. After three hours the eggs were returned to normal sea-water and fertilized. Next day it was found that the great majority of mature eggs had formed

[1] Cf. R. S. Lillie, *loc. cit.*, p. 6.

active and vigorous blastulæ and gastrulæ, while of the untreated control eggs left in sea-water and fertilized at the same time as the others less than one per cent. formed larvæ and these were feeble and abnormal. It thus appeared that the abnormal condition which renders the egg incapable of responding fully to the fertilizing action of the spermatozoön might be removed by treatment with sea-water containing ether in certain concentrations, which are considerably lower than those required for typical anæsthetic or protective action.

What are the conditions of this effect? In a recent paper[1] I have presented evidence indicating that the protective and anæsthetic actions exerted by ether and other lipoid-solvents in certain concentrations are due primarily to a *modification of the plasma membranes* of the cells or irritable elements, of such a kind as to render these membranes more resistant toward agencies that under the usual conditions rapidly increase their permeability; cytolysis and stimulation, both of which depend on such increase of permeability, are hence checked or prevented. Decrease in the readiness with which the permeability is increased thus involves for an irritable tissue decreased irritability; this effect is produced by various salts, *e. g.*, of magnesium, and by ether and other lipoid-solvent anæsthetics in certain (not too high) concentrations. In lower concentrations it has been observed that ether and other lipoid-solvents frequently *heighten* irritability;[2] *i. e.*, expressed in terms of the membrane theory of stimulation, they increase the readiness with which the permeability—and hence the electrical polarization—of the plasma membrane undergoes change. It seems clear that for irritable tissues the state of the lipoids in the plasma membrane largely determines the readiness with which changes of permeability—and of the dependent electrical polarization—are induced by external agencies. Slight permeation of the lipoids with a lipoid-solvent like ether apparently often facilitates such changes and hence in-

[1] R. S. Lillie, *American Journal of Physiology*, 1912, Vol. 29, p. 372.

[2] For various instances of this effect cf. the references cited in my recent paper in *American Journal of Physiology*, 1912, Vol. 29, p. 374. The neuromuscular system of marine animals also shows it; *e. g.*, Bethe found that alcohol (0.5 per cent. in sea-water) decidedly increased the mechanical irritability of the isolated central portion of the medusa *Cotalorrhiza;* cf. "Allgemeine Anatomie und Physiologie des Nervensystems," Leipzig, 1903, p. 359.

creases irritability; the presence of more lipoid-solvent renders a change of permeability difficult,[1] hence the protective or anæsthetic action; while concentrated solutions of lipoid-solvents disrupt the membrane and produce cytolytic or irreversible alterations in the cells; hence such substances in higher concentrations are markedly toxic.

On the assumption that lipoid-solvents influence the plasma membranes of egg cells in essentially the same manner as those of irritable tissues, the above action of ether on abnormal egg cells becomes more readily intelligible; it falls, in fact, into the same essential category with the facts just cited. There is a close analogy between the stimulation of irritable tissues and the initiation of cleavage in egg cells; the primary or critical change in both cases appears to be a temporary and reversible increase in the permeability of the plasma membrane, with accompanying changes in the electrical polarization of the latter.[2] This analogy suggests that the irresponsive condition of the above "overripe" starfish eggs is essentially the symptom or expression of an abnormal condition of the plasma membrane. Apparently the latter has in these eggs become *abnormally resistant to changes of permeability;* hence the eggs are irresponsive to the spermatozoön (whose primary action is to increase permeability); hence also they show heightened resistance to cytolytic action—which also depends on increase in surface permeability; this is shown by the slowness with which they undergo the typical postmaturational cytolysis, and also by their increased resistance to pure isotonic sodium chloride solution. If this interpretation is correct, the favorable action of weak ether solution consists essentially in altering the plasma membrane and rendering it more susceptible to the action of permeability-increasing (and hence depolarizing) agencies—*i. e., more irritable*, on the above-mentioned analogy with irritable tissues. Through this means the plasma membrane is restored to an approximately normal condi-

[1] This is very clearly shown in the larvæ of *Arenicola;* cf. the paper just cited, p. 380 ff.

[2] I have discussed the probable basis of this resemblance at some length in an earlier paper in the BIOLOGICAL BULLETIN, 1909, Vol. 17, pp. 20 ff. The title of Loeb's recent book, "Entwicklungserregung des tierischen Eies," also emphasizes this analogy.

tion of responsiveness; the sperm then exhibits its normal action. It is evident that this hypothesis also implies that the other changes in the egg expressive of increased permeability should, after the ether treatment, also follow an approximately normal course. This in in fact the case as regards the post-maturational cytolysis; this change is delayed in the above abnormal eggs, as already described; but it is found to take place in a normal manner in the ether-treated unfertilized eggs. The following descriptions will illustrate both of these effects.

It should first be noted that the degree to which eggs abnormally resistant to fertilization may be rendered normal by the ether treatment is variable. In some of my last summer's experiments the difference between the ether-treated and the untreated eggs of the same lot was slight; in others the contrast was most striking. The degree of resistance to the post-maturational cytolysis is similarly variable. In general it was observed that eggs which showed the most pronounced delay in the onset of this latter change were most readily brought into a normally responsive condition—or "rejuvenated"—by ether. The following series of experiments with three separate lots of starfish eggs—all of which failed with a few exceptions to develop to a blastula stage on simple fertilization without ether treatment—illustrates this variability, as well as the correlation between delay in the post-maturational cytolysis and the possibility of rejuvenation[1] by the ether treatment.

June 30, 1911. Three separate lots of eggs (*A*, *B*, *C*) were used; each lot consisted of the mixed eggs from several starfish. After remaining about one and a half hours in normal sea-water, eggs from each lot were transferred to sea-water containing 0.3 vol. per cent. ether. These eggs were kept in small tightly corked flasks. After 1 hour and 10 minutes in this solution part of the eggs were transferred from each flask to normal sea-water in finger bowls; after washing the eggs free from ether spermatozoa were added. The remainder of the eggs in each flask were similarly transferred to sea-water and fertilized after three and a quarter hours in the ether solution. For each lot there was a *fertilized control* consisting of eggs which had lain untreated in sea-water for about 2 hours and 45 minutes before fertilization.

[1] I use this term because of the analogies it suggests. The eggs are in fact brought by the ether treatment into a condition which is characteristic of eggs produced in the earlier portion of the reproductive cycle. The production of hyper-resistant eggs like the above occurs late in the breeding season, and the phenomenon bears certain analogies to senescence. See below, page 345.

The characteristics and behavior of the eggs from these three lots were respectively as follows:

LOT A.—The great majority of these eggs fail to maturate. A small proportion undergo apparently normal maturation.

Unfertilized Eggs.—22 hours after removal almost all of the mature eggs show the typical opaque and coagulated protoplasm; *i. e.*, post-maturational cytolysis appears normal.

Fertilized Eggs.—Condition *ca.* 20 hours after fertilization.

1. *Untreated (Control) Eggs.*—Many of the immature eggs have typical fertilization membranes; but are otherwise unchanged. The few mature eggs are mostly dead; only one abnormal blastula was found.

2. *Ether-treated Eggs.*—(*a*) Exposed 1 hour 10 minutes. Four or five blastulæ are found in some hundred eggs; little difference from control. (*b*) Exposed 3¼ hours. Little or no improvement over control; a few blastulæ as in (*a*).

LOT B.—Most of these eggs remain immature, but about 20 per cent. undergo apparently normal maturation.

Unfertilized Eggs.—22 hours after removal from the animals most of the mature eggs are opaque and coagulated, but in many the coagulation is less advanced than in normal eggs, and in some the protoplasm remains semi-translucent.

Fertilized Eggs.—Condition *ca.* 20 hours after fertilization.

1. *Untreated (Control) Eggs.*—Almost all of the mature eggs are dead. Many immature eggs have fertilization membranes. Only two abnormal blastulæ are found in several hundred eggs.

2. *Ether-treated Eggs.*—(*a*) Exposed 1 hour 10 minutes. Improvement over the control; a large proportion (about one third) of the mature eggs have formed blastulæ, many of which have begun to gastrulate. (*b*) Exposed 3¼ hours. Also shows a marked improvement over the control, but the larvæ are fewer and less active than in 2*a*.

LOT C.—In this lot of eggs the majority show normal maturation, though a few remain immature.

Unfertilized Eggs.—After 22 hours in sea-water most of the eggs are more or less coagulated, but the degree of opacity is distinctly less than in normal eggs, and a considerable proportion remain translucent—almost like freshly shed eggs.

Fertilized Eggs.—Condition *ca.* 20 hours after fertilization.

1. *Untreated (Control) Eggs.*—Nearly all are dead. Most have membranes and show evidence of having cleaved or fragmented, but many have failed to cleave or even to form membranes. A small proportion of eggs have formed larvæ some of which appear normal: the larvæ though few are more numerous than in the controls of *A* and *B*.

2. *Ether-treated Eggs.*—(*a*) Exposed 1 hour 10 minutes. Striking contrast to control. Almost all of the mature eggs have formed active larvæ, many in the early gastrula stage and swimming at the surface of the water. (*b*) Exposed 3¼ hours. Here also the majority of eggs form larvæ, but these are largely abnormal, and relatively few gastrulæ or surface swimmers are present.

The power of development after fertilization is thus greatly increased after ether-treatment in Lots *B* and *C*, but not in Lot *A*. The mature eggs of Lots *B* and *C* show marked delay in the post-maturational cytolysis; in Lot *C* this delay is greater, and the

action of the ether is correspondingly more favorable, than in Lot *B*. I have already presented evidence that eggs showing this abnormal behavior are characterized by the possession of hyper-resistant plasma membranes. It should be noted that variations in the degree of resistance of this membrane occur regularly in normal eggs. Various facts indicate that the process of maturation is constantly associated with a change in the properties of the plasma membrane. This is shown by the fact that mature eggs undergo cytolysis in 0.55*m* NaCl solution more rapidly than immature eggs;[1] also by the fact that contact with spermatozoa and various forms of artificial treatment cause the separation of the surface-film of mature eggs in the form of a fertilization membrane, a change indicating a superficial cytolytic or permeability-increasing action; while immature eggs are not normally subject to this change.[2] This difference between immature and mature eggs is a constant or physiological feature in the life history of these eggs. The difference between normal eggs and the resistant eggs under consideration is in many respects similar. For some reason the maturation process fails to bring these eggs into the normally sensitive condition in which the permeability of the membrane is readily increased. Hence fertilization is imperfect, even fertilization-membranes failing to form in some cases; in others membranes are formed and cleavage begins, but the latter is characteristically irregular and fails to proceed far. According to this view the failure of development is due not to defective organization of the protoplasm, but simply to the existence of an abnormally resistant plasma membrane. The action of ether consists in restoring the membrane to its normal condition. The response to the spermatozoön then becomes normal.

The experimental evidence in favor of this hypothesis consists at present simply in the fact that such abnormal eggs are rendered normal by ether treatment not only in regard to their response to fertilization, but also in regard to the rate and character of

[1] R. S. Lillie, *American Journal of Physiology*, 1912, Vol. 30, p. —.

[2] Cf. J. Loeb's experiments on the eggs of *Asterina*, University of California Publications, Physiology, 1905, Vol. 2, p. 150. Spermatozoa and artificial membrane-forming agencies may however produce typical membranes in abnormal immature starfish eggs. Cf. *Journal of Experimental Zoölogy*, 1908, Vol. 5, p. 407.

the spontaneous post-maturational cytolysis; *i. e.*, they undergo complete coagulation within eighteen hours or less, precisely as do normal eggs. Whether the resistance to cytolysis by salt solutions is also decreased I have not yet determined; but the decrease in the resistance to the post-maturational cytolysis—a change supposedly due to the action of certain protoplasmic oxidation products upon the plasma membrane[1]—is clear evidence that the membrane has been brought into a condition more nearly approaching the normal. The experiments to be described show that a return of the normal responsiveness to the spermatozoön is closely correlated with a return of the normal behavior with respect to this spontaneous oxidative cytolysis. In other words, the plasma membranes of the ether-treated "rejuvenated" eggs undergo breakdown in the manner and at the time characteristic of normal eggs.

The following record gives the description of two typical experiments.

July 6, 1911. Eggs were removed at 11:00 A.M. from two lots of starfish, *A* and *B*. In both lots a good proportion of eggs underwent apparently normal maturation. Eggs from each lot were divided into two portions. One portion remained in sea-water; and about four hours after removal from the animals part of these eggs were fertilized; the rest remained unfertilized. The other portion was transferred, two hours after removal, to sea-water containing 0.3 vol. per cent. ether; in this solution they remained for one hour and thirty-five minutes; they were then returned to sea-water; to part of these eggs spermatozoa were added, the rest remained unfertilized. The ether-treated and the untreated eggs were fertilized at the same time. The two lots *A* and *B* were treated alike so far as possible. The results of these experiments were as follows:

Lot A. The following was the condition of the eggs *ca.* 22 hours after removal:

1. *Untreated Eggs.* (*a*) *Unfertilized.*—Most mature eggs are coagulated but to a varying degree; some are only slightly darkened, and in a fair proportion the protoplasm remains semi-translucent.

(*b*) *Fertilized.*—All of the mature eggs have formed membranes and most have undergone cleavage or irregular fragmentation; but many remain uncleaved; no blastulæ are present.

2. *Ether-treated Eggs.*—(In 0.3 vol. per cent. ether from 1.00 to 2.35 P.M.)

(*a*) *Unfertilized.*—All mature eggs are completely and uniformly coagulated; there are no partly coagulated or semi-translucent eggs.

(*b*) *Fertilized.*—Decided contrast to 1*b*. Most eggs are dead, but among these there are no uncleaved eggs; numerous blastulæ and gastrulæ are present, many swimming at the surface.

Lot B.—(The condition of the eggs *ca.* 22 hours after removal.)

[1] Since the change is greatly retarded in oxygen-free or cyanide-containing sea-water. Cf. J. Loeb, *Archiv für die gesammte Physiologie*, 1902, *loc. cit.*

1. *Untreated eggs.*—(*a*) *Unfertilized.*—The degree of post-maturation coagulation varies here as in Lot *A*, but a larger proportion of eggs remain semi-transclucent, and many are virtually unchanged in appearance.

(*b*) *Fertilized.*—Most eggs have formed membranes and cleaved or fragmented; a number form membranes but fail to cleave. A few feeble blastulæ are present—a fraction of 1 per cent.; no surface swimmers.

2. *Ether-treated eggs.*—(In 0.3 vol. per cent. ether from 1.00 to 2.35 P.M.)

(*a*) *Unfertilized.*—Marked contraxt to 1*a*. All mature eggs are completely coagulated—opaque, compact looking, without membranes.

(*b*) *Fertilized.*—A large number of active blastulæ and gastrulæ are present, many swimming at the surface. No uncleaved eggs are present, though a good many have died in early stages. More favorable than *A*, 2 (*b*).

The return of the normal responsiveness to fertilization and normal power of development is thus associated with a return of the normal rate of post-maturational cytolysis. This observation was made in six out of nine experiments, at different times and with different lots of eggs, in which ether-treatment led to marked increase in the proportion of eggs undergoing favorable development. In three of the earlier experiments the behavior of the ether-treated unfertilized eggs was not observed; but in all of the six cases where both observations were made concurrently this correlation held. As already mentioned, the degree of improvement effected by the ether has been variable, in correspondence with the degree of abnormality in the eggs. In all of the cases in which the improvement was decided, as in some of those described above, the untreated mature eggs proved largely refractory toward both cytolysis and fertilization; while after the treatment with ether the eggs showed in both respects a behavior approaching the normal. In three other lots of abnormal eggs treatment with ether had no appreciable effect either in accelerating cytolysis or in increasing the proportion of favorably developing eggs; while in one case in which a considerable proportion of untreated eggs developed favorably—about one third forming larvæ—the ether-treated eggs were somewhat *less* favorable than the untreated; in this series the unfertilized eggs, both treated and untreated, showed an apparently normal spontaneous cytolysis. Probably the plasma membranes of these eggs were over-susceptible rather than under-susceptible to increase of permeability. The possible existence of both kinds of abnormalities must be recognized.

Deviation in either direction from the physiological norm would presumably impair the power of development.

General Discussion.

I shall now discuss somewhat more fully the general physiological significance of the above abnormalities and their relations to analogous conditions elsewhere. The above condition, described in general terms, is essentially one of lowered susceptibility to agencies which ordinarily call forth a definite response. Similar conditions exist in other cells and tissues. There are also cases where a tissue is normally irresponsive to certain agencies or conditions, to which however it may be rendered responsive by certain forms of artificial treatment.[1] It seems probable that in all of these cases the condition of the plasma membrane is the essential factor which determines whether the cell or tissue responds to the agency in question or not. This structure, as the most external layer of the cell, is the part most accessible to artificial modification; and if its condition of permeability and electrical polarization plays the controlling rôle in cell-processes which modern investigation tends more and more to indicate, knowledge of the means by which its properties may be altered at will becomes a matter of the highest importance for both the theoretical and the practical aspects of biology.

The abnormalities under consideration appear typically in the eggs of *Asterias forbesii* toward the close of the breeding season. Eggs are abundant at Woods Hole in early June.[2] During the greater part of this month they exhibit as a rule a normal response to fertilization; and if left unfertilized in sea-water at 20° they undergo the above described coagulative

[1] Instances of this are seen in various phenomena of sensitization. A good instance is the hypersensitiveness to contact induced in frog's skeletal muscle by isotonic solutions of sodium citrate, tartrate, sulphate, and certain other salts. Cf. J. Loeb, *American Journal of Physiology*, 1901, Vol. 5, p. 362.

[2] In former years a considerable proportion of starfish collected in August and September have yielded numerous normal eggs. Probably these starfish were of a different species from the above—presumably *A. vulgaris*. During the last few years this form seems to have become rare in the neighborhood of Woods Hole, and eggs have been difficult to obtain later than June. Two species of *Asterias*, *forbesii* and *vulgaris*, are recognized as occurring in this region; cf. H. L. Clark, Bulletin of the U. S. Fish Commission, 1902, p. 552.

cytolysis within 12 to 15 hours or less. Toward the end of June eggs become fewer and more variable in quality, many fail to maturate and the mature eggs on fertilization tend to cleave irregularly and largely die before reaching the blastula stage; a large proportion of eggs show the abnormalities described above; increased resistance to fertilization and to cytolytic alteration is especially characteristic and indicates that the plasma membrane has become abnormally resistant to changes in permeability.

I have described the peculiarities of these eggs in sufficient detail above, and have already briefly discussed the physiological nature of the abnormalities. The failure to respond normally to fertilization becomes intelligible on the hypothesis that the essential or critical event in the initiation of cell-division is a temporary and reversible increase in the ionic permeability of the plasma membrane. Such a change involves a decrease in the electrical polarization of the membrane, and it appears probable—as in the analogous case of muscle and nerve—that this change of polarization, and not the mere increase of permeability as such, is the critical event which initiates the rhythmical series of physical and chemical processes of which cleavage is the normal expression.[1] In order that the egg may respond to the contact and entrance of the spermatozoön in a normal manner, its plasma membrane must have a certain definite physico-chemical constitution such that the substances transmitted by the spermatozoön[2] may effect an increase of permeability which in rate and degree approximates a certain norm. This implies a certain degree of resistance to change of permeability; if this resistance is abnormally great, the response fails to occur or is imperfect; if abnormally low, the spermatozoön effects too great and too lasting an increase in permeability

[1] The astral radiations of mitosis are probably the expression of potential differences between different regions of the cell, arising in consequence of altered polarization of the limiting membranes. The alternate appearance and disappearance of the radiations indicates a rhythm of changing polarization of the limiting membranes. For a further discussion cf. my papers in BIOLOGICAL BULLETIN, 1909, *loc. cit.*; *Amer. Jour. Physiol.*, 1910, Vol. 26, pp. 128 ff.; *Journal of Morphology*, 1911, Vol. 22, p. 711.

[2] According to Loeb, certain lysin-like bodies (cf. "Entwicklungserregung," p. 247). I have suggested calling these "membranolysins" to indicate the essential nature of their action.

resulting in early death or cytolysis—just as occurs in eggs subjected to a simple membrane-forming treatment without subsequent exposure to hypertonic sea-water.[1] Eggs which begin cleavage, but fragment and break down before proceeding far in development, possibly belong to this latter class. If normal development is to follow fertilization, the properties of the plasma membrane cannot, on the present hypothesis, depart widely from a constant mean or physiological norm.

The failure of the above eggs to respond normally to fertilization, as also their resistance to cytolysis, is thus to be regarded as the expression of a highly resistant condition of the plasma membrane. The latter fails readily to undergo the increase of permeability essential to these changes,—probably because of abnormalities in the nature, state, or proportions of its chemical constituents. The essential effect of the treatment with ether is to restore the normal properties of the membrane. There is, however, no reason to believe that this effect is specific to ether. In some of my last summer's experiments a similar though less favorable effect was produced by exposure to isotonic sodium chloride solution and—in one case—to a 0.1 per cent. solution of chloral hydrate in sea-water. In its general form the problem relates to the essential nature of the modification which these substances induce in the egg, and by which the latter is brought from an irresponsive condition into one in which it shows a normal response. Light is thrown on this problem by the conditions in irritable tissues such as muscle and nerve.

A close analogy exists between the initiation of cell-division in eggs or other resting cells, and the response of an irritable tissue to stimulation. In both cases the initial or critical event is apparently a temporary increase in surface-permeability, with accompanying changes in the electrical polarization of the limiting membranes. The means by which refractory eggs may

[1] The second part of the treatment appears to effect a return of the permeability—which has been increased by the membrane-forming treatment—to the normal (cf. *Amer. Jour. Physiol.*, 1911, Vol. 27, p. 289). Godlewski (*Archiv für Entwicklungsmechanik*, 1911, Vol. 33, p. 225) has independently reached a similar conclusion with regard to the essential nature of the effect produced by the hypertonic sea-water.

be rendered normally responsive is thus analogous to that by which the responsiveness of muscle and nerve to stimulation may be increased. An irresponsive condition in living muscle and nerve may be due to anæsthesia, fatigue, electrotonus, toxic action, or other changes of state. The stimulating action of small doses of alcohol[1] and other narcotics during fatigue suggests an analogy which is probably not without significance. It is known that traces of various lipoid-solvent substances very generally increase irritability, or the rate of spontaneous activity, in the most various cells and tissues (leucocytes, cilia, the heart, etc.).[2] The increased responsiveness of the above eggs after ether treatment is a phenomenon of the same general kind. It would appear that the condition of the lipoids in cells determines the readiness of response or the rate of spontaneous activity; and that slight impregnation of the lipoids in the membrane with a lipoid-solvent facilitates in this structure the alteration which conditions the permeability-increase and polarization-change of stimulation.

Certain salts markedly increase the irritability of muscle and nerve,—*i. e.*, induce sensitization.[3] Treatment with salt solutions may also restore fatigued muscles to an irritable condition. Frog's skeletal muscles immersed in isotonic sodium chloride solution and made to contract by successive electrical stimuli until irresponsive promptly recover irritability if immersed in isotonic sodium bromide, nitrate or iodide solutions. Sodium iodide restores irritability to muscles which have been fatigued in sodium bromide or nitrate solutions, but chloride has no such action; *i. e.*, the order of the salts cannot be reversed. The restorative effect is rapid, and evidently depends on a surface action, the colloids of the membrane being apparently brought into a condition favorable for stimulation—apparently a condition of increased dispersion.[4] As already described, sodium chloride solution may produce an analogous increase of respon-

[1] The action of small quantities of alcohol in counteracting fatigue in excised frog muscles has been well shown by Lee and Salant, *Amer. Jour. Physiol.*, 1902, Vol. 8, p. 61.

[2] Cf. footnote 2, page 331.

[3] Cf. footnote 1, page 338.

[4] C. Schwarz, *Archiv für die gesammte Physiologie*, 1907, Vol. 117, p. 161.

siveness in refractory starfish eggs. Schwarz's observations, as well as my own with abnormal starfish eggs, thus belong to that general class of cases in which the responsiveness of cells is increased by treatment with salts or low concentrations of lipoid-solvents. The response of voluntary muscle to various forms of chemical stimulation may be increased by brief immersion in isotonic solutions of various sodium salts; in the case of salts which do not precipitate calcium, this sensitizing action increases with variation in the nature of the anion in the following general order: $Cl < Br < NO_3 < ClO_3 < CNS$ and I, an order corresponding to the order of increasing effectiveness in promoting colloidal dispersion.[1] Interpreted in terms of the membrane theory, these facts mean that the readiness with which the plasma membrane undergoes increase in permeability may be increased either by altering the general state of the colloids in the membrane, or by slightly altering that of the lipoids alone.

We conclude that the effect produced by salts and weak ether solutions in increasing the responsiveness of refractory eggs to fertilization is comparable with the sensitization of irritable tissues by these substances; also that in both cases the essential change consists in an increase in the readiness with which the plasma membrane undergoes the critical change of permeability and of electrical polarization.

It is to be noted that the resistance of eggs to fertilization by foreign sperm may also be decreased by chemical treatment, as Loeb discovered several years ago.[2] Heightening the alkalinity of the medium has this effect. This characteristic and striking effect is probably an expression of a very general action of weak alkali. Many facts indicate that slight increase in the alkalinity of the medium usually increases the readiness with which the permeability of cells is altered: cell-division is accelerated, the irritability of irritable tissues and the rate of activity of automatic tissues is increased, the cytolytic action of salt solutions is accelerated, and in unfertilized eggs membrane formation and the initiation of cleavage may be induced.[3] It remains to be determined whether

[1] R. S. Lillie, *Proceedings of the Society for Experimental Biology and Medicine*, New York, 1910, Vol. 7, p. 170.

[2] J. Loeb, University of California Publications, Physiology, 1903, Vol. 1, p. 1.

[3] Cf. J. Loeb, *Archiv für die gesammte Physiologie*, 1907, Vol. 118, p. 7.

alkali as well as ether can overcome the resistance of over-ripe starfish eggs to fertilization by their own sperm; also whether treatment with weak solutions of ether or other lipoid-modifying substances, as well as with weak alkali, can render cross-fertilization possible. The case of the eggs of hermaphrodite animals, which are irresponsive to sperm from the same individual but not to that of other individuals, may possibly belong in part to the present category. Morgan[1] found that the eggs of *Ciona*, which furnish a typical instance of this behavior, could be fertilized by spermatozoa from the same individual in weak solutions of ether, ammonia or alcohol; but he is inclined to attribute the effect to the stimulating action of these substances on the sperm, rather than to an alteration of the egg. In one experiment, however (p. 147), in which the spermatozoa alone were treated with ether before adding to the egg, few eggs were fertilized, while when both eggs and sperm were so treated the percentage of fertilization was high (in one case 85 per cent. as compared with 4 per cent.). This experiment suggests that the ether produces its effect not merely by increasing the motility of the sperm, but also by altering the condition of the egg, as in the case of *Asterias*. Another interesting case in which the egg is rendered refractory to fertilization has recently been described by Godlewski.[2] If the spermatozoa of *Chætopterus* and of *Sphærechinus* are mixed, both are found after a few minutes to have completely lost the power of fertilizing the eggs of *Sphærechinus*.[3] Eggs left exposed to this

[1] Morgan, *Journal of Experimental Zoölogy*, 1904, Vol. 1, p. 135.

[2] Godlewski, *Archiv für Entwicklungsmechanik*, 1911, Vol. 33, p. 233.

[3] The spermatozoa in this mixture retain their motility in spite of their having ost the power of affecting the egg (*loc. cit.*, p. 240). It would be interesting to know if the motility undergoes *any* decrease. Apparently the surface layer of the spermatozoön is modified, since there is no transmission of membranolysins to the egg. This would imply heightened resistance to permeability-change in the plasma membrane of the spermatozoön; and such a change would presumably involve decreased motile activity—*i. e.*, a slower rhythm in the variation of ionic permeability and polarization conditioning the movements. Various facts indicate that in normal fertilization the spermatozoön and the egg affect each other *mutually* in a somewhat similar manner, and that a cytolytic or permeability-increasing action is exercised by the egg upon the sperm as well as by sperm upon the egg. Thus the sperm usually ceases its movements soon after contact with the egg, and often only a portion enters the latter; a cytolytic or disintegrative change in the spermatozoön is thus indicated. The plasma membrane of the sperm might—as apparently in Godlewski's experiments—be rendered sufficiently hyper-resistant to prevent this mutual cytolytic action without entire loss of motility.

sperm mixture are at first unaffected, but in the course of half an hour they become so modified that fertilization with normal *Sphærechinus* sperm is impossible. The egg is thus deprived of the power of response to its own spermatozoa.[1] Whether this condition of irresponsiveness (which is comparable to paralysis) may be removed by artificial treatment such as the above has apparently not been determined; but from the analogies with the conditions just described there is every reason to believe that this would readily be found possible.[2]

In conclusion I wish briefly to indicate the bearing of the above observations on the general theory of pathological alterations in cells. The conclusion that many pathological conditions have their primary origin in abnormalities of the limiting membranes of cells is an obvious corollary of any view that regards such membranes—which are essentially insulating surface-films of varying ionic permeability and electrical polarization—as largely controlling the rate and character of the cell-processes. If stimulation depends primarily on altered polarization of the plasma membrane due to increased ionic permeability, it is clear that a normal response, in the case of any cell, implies a definite condition of the membrane. If this condition is permanently altered the cell processes inevitably undergo derangement, and pathological changes follow. Such a deranged condition, if not too far advanced, may be rectified by restoring the membrane to its normal condition. How this may be accomplished is illustrated by the case of the abnormal starfish eggs described above. It is clear from the cytolytic effects produced by many toxines that they cause abnormal increase in the permeability of the membranes; and in all probability their destructive action is in many cases directly due to this surface action. The alteration caused by a toxic agent may consist primarily either in increasing or in decreasing the permeability normal to the membrane, or in altering in either direction the readiness with which the latter undergoes change. Evidently the plasma membrane, as an

[1] A similar and reversible effect may be produced by treating the egg with certain salt solutions, as Mathews and Newman showed some years ago for *Fundulus* eggs; cf. BIOLOGICAL BULLETIN, 1905, Vol. 9, p. 378.

[2] Evidence that this change is in fact reversible is seen in the effects of washing the eggs thoroughly in sea-water after the treatment with the sperm mixture. A partial return of responsiveness to the spermatozoön was observed (p. 236).

insulating—and hence semi-permeable—layer on the integrity of which the normal composition of the living substance depends, cannot undergo marked and prolonged increase of permeability without alteration in the nature and proportion of the cell-constituents; this involves altered chemical organization and eventual derangement of the cell-processes.[1] In most of the abnormal conditions considered above the membrane appears to have undergone the opposite kind of modification, becoming abnormally impermeable and resistant to changes of permeability. Such a condition is essentially one of irresponsiveness, and is in a sense pathological, although it differs from a condition of permanently increased permeability in involving no loss of material from the cell; hence the possibility of restoring the normal properties of the cell—by bringing the permeability again to the normal—should theoretically be greater in this class of cases than in the other.[2]

Perhaps the condition of the above resistant starfish eggs is not properly to be called pathological, since the change in the properties of the eggs toward the close of the breeding season is presumably a constant one, and hence normal in a physiological sense. The eggs merely become hyperresistant to fertilization; *i. e.*, with increasing age the metabolism of the ovaries undergoes alteration so as to lead to the production of eggs having more resistant membranes than before. The cycle of egg-production shortly afterwards comes to a close. The phenomenon bears in certain respects a marked resemblance to senescence, and its conditions may throw light on the physiology of the latter process. In old age the irritable tissues become less and less responsive, and the rate of metabolism is correspondingly lowered. Irre-

[1] I have dwelt on these considerations at somewhat greater length in my earlier paper in this journal, 1909, Vol. 17, p. 197 et seq. The fundamental importance of the part which alterations of the membranes play in pathological processes was first recognized by Zangger. The following quotation will illustrate: "Die normale typische Permeabilität der Membranen ist also Voraussetzung der normalen Lebensfunktionen. Dauernd veränderte Permeabilität der Membranen bedeutet Pathologie, pathologischen Stoffwechsel," etc.: Vierteljahrsschrift d. Naturf. Ges. Zürich, 1906, Vol. 51, p. 432. Cf. also *ibid.*, 1907, 1908, and the other papers of Zangger and his students, especially Frei and Stoffel, for a fuller development of these ideas, together with experimental data bearing on the relations of membrane changes to pathological processes, immunity, and related phenomena.

[2] For further discussion of this subject cf. my earlier paper in *American Jour. Physiol.*, 1910, Vol. 26, pp. 112 et seq.

sponsiveness, as already pointed out, implies a state of the plasma membrane in which changes of permeability and of electrical polarization are produced with difficulty. The increasingly resistant character of the membranes implies altered composition. Possibly the condition in over-ripe eggs, as well as in senescence, results from a progressive accumulation or adsorption at the phase-boundaries, *i. e.*, in the membranes, of materials which for some reason are not readily eliminated by the organism.[1] A similar view has recently been expressed by Child.[2] According to his theory "senescence in nature consists physiologically in a decrease in the rate of metabolism, and this is determined morphologically by the accumulation in the cell of structural obstacles to metabolism, *e. g.*, decrease in permeability, increase in density, accumulation of relatively inactive substances, etc." Minot's[3] theory that senescence is the expression of a progressively increasing differentiation of cells, *i. e.*, of an increase in the proportion of separated solid structural material, bears a certain resemblance to this view. The view which I have suggested above is distinctive only in so far as it attributes the essential change to a modification of the *membranes*. It is, theoretically at least, within the possibilities of physiological science to prevent or retard this accumulation of inert materials in the membranes and so to delay senescence. Or the already modified membranes might, if not too profoundly altered, be restored to a normal condition by certain forms of treatment. The simpler the metabolism and the less widely differentiated the tissues, the greater would appear to be the possibility of such "rejuvenescence" of the organism as a whole. In one large group, the Protozoa senescence seems not to be an inevitable occurrence; the earlier interpretation of conjugation as a process whose essential rôle is to counteract an innate tendency to senescence has been discredited by the work of Calkins and Woodruff. The conditions in Metazoa differ from those in Protozoa chiefly in their greater complexity, but probably in no other essential respect.

[1] Probably certain colloidal (*i. e.*, indiffusible) and chemically refractory by-products of metabolism.

[2] Cf. Child, *Archiv für Entwicklungsmechanik*, 1911, Vol. 31, p. 537.

[3] C. S. Minot, "The Problem of Age, Growth and Death." New York and London, 1908.

THE MARINE BIOLOGICAL LABORATORY

FOURTEENTH REPORT

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[1] Deceased.

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H. S. JENNINGS.....Johns Hopkins University.
GEORGE LEFEVRE.....University of Missouri.
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G. H. PARKER.....Harvard University.

II. ACT OF INCORPORATION

No. 3170.

COMMONWEALTH OF MASSACHUSETTS

Be It Known, That whereas Alpheus Hyatt, William Sanford Stevens, William T. Sedgwick, Edward G. Gardiner, Susan Minns, Charles Sedgwick Minot, Samuel Wells, William G. Farlow, Anna D. Phillips and B. H. Van Vleck have associated themselves with the intention of forming a Corporation under the name of the Marine Biological Laboratory, for the purpose of establishing and maintaining a laboratory or station for scientific study and investigation, and a school for instruction in biology and natural history, and have complied with the provisions of the statutes of this Commonwealth in such case made and provided, as appears from the certificate of the President, Treasurer, and Trustees of said Corporation, duly approved by the Commissioner of Corporations, and recorded in this office;

Now, therefore, I, HENRY B. PIERCE, Secretary of the Commonwealth of Massachusetts, *do hereby certify* that said A. Hyatt, W. S. Stevens, W. T. Sedgwick, E. G. Gardiner, S. Minns, C. S. Minot, S. Wells, W. G. Farlow, A. D. Phillips, and B. H. Van Vleck, their associates and successors, are legally organized and established as, and are hereby made, an existing Corporation, under the name of the MARINE BIOLOGICAL LABORATORY, with the powers, rights, and privileges, and subject to the limitations, duties, and restrictions, which by law appertain thereto.

Witness my official signature hereunto subscribed, and the seal of the Commonwealth of Massachusetts hereunto affixed, this twentieth day of March, in the year of our LORD ONE THOUSAND, EIGHT HUNDRED AND EIGHTY-EIGHT.

HENRY B. PIERCE,
Secretary of the Commonwealth.

[SEAL.]

III. BY-LAWS OF THE CORPORATION OF THE MARINE BIOLOGICAL LABORATORY

I. The annual meeting of the members shall be held on the second Tuesday in August, at the Laboratory, in Woods Hole, Mass., at 12 o'clock noon, in each year, and at such meeting the members shall choose by ballot a Treasurer and a Clerk, who shall be, *ex officio*, members of the Board of Trustees, and Trustees as hereinafter provided. At the annual meeting to be held in 1897, not more than twenty-four Trustees shall be chosen, who shall be divided into four classes, to serve one, two, three, and four years, respectively, and thereafter not more than eight Trustees shall be chosen annually for the term of four years. These officers shall hold their respective offices until others are chosen and qualified in their stead. The Director and Assistant Director, who shall be chosen by the Trustees, shall also be Trustees, *ex officio*.

II. Special meetings of the members may be called by the Trustees, to be held in Boston or in Woods Hole at such time and place as may be designated.

III. The Clerk shall give notice of meetings of the members by publication in some daily newspaper published in Boston at least fifteen days before such meeting, and in case of a special meeting the notice shall state the purpose for which it is called.

IV. Twenty-five members shall constitute a quorum at any meeting.

V. The Trustees shall have the control and management of the affairs of the Corporation; they shall present a report of its condition at every annual meeting; they shall elect one of their number President and may choose such other officers and agents as they may think best; they may fix the compensation and define the duties of all the officers and agents; and may remove them, or any of them, except those chosen by the members, at any time; they may fill vacancies occurring in any manner in their own number or in any of the offices. They shall from time to time elect members to the Corporation upon such terms and conditions as they may think best.

VI. Meetings of the Trustees shall be called by the President, or by any two Trustees, and the Secretary shall give notice thereof by written or printed notice sent to each Trustee by mail, postpaid. Seven Trustees shall constitute a quorum for the transaction of busi-

ness. The Board of Trustees shall have power to choose an Executive Committee from their own number, and to delegate to such Committee such of their own powers as they may deem expedient.

VII. The President shall annually appoint two Trustees, who shall constitute a committee on finance, to examine from time to time the books and accounts of the Treasurer, and to audit his accounts at the close of the year. No investments of the funds of the Corporation shall be made by the Treasurer except approved by the finance committee in writing.

VIII. The consent of every Trustee shall be necessary to a dissolution of the Marine Biological Laboratory. In case of dissolution, the property shall be given to the Boston Society of Natural History, or some similar public institution, on such terms as may then be agreed upon.

IX. These By-Laws may be altered at any meeting of the Trustees, provided that the notice of such meeting shall state that an alteration of the By-Laws will be acted upon.

X. Any member in good standing may vote at any meeting, either in person or by proxy duly executed.

IV. TREASURER'S REPORT

For the Year Ending December 31, 1911

Income

Annual dues		$ 728.00	
Donations		13,412.00	
Homestead, general account (net)		1,111.93	
Miscellaneous:			
Interest on deposits	$97.06		
Rent of microscopes	9.90		
Use of drain (4 years)	16.00	122.96	
Supply department		10,303.61	
Tuitions		4,574.99	$30,253.49

Expenses[1]

Administration	$3,044.22
Advertising and printing	137.26
Bath house	96.91
Biological Bulletin (net)	1,082.66
Boats	6,003.45
Chemical department	838.44
Dormitories	72.97
Fish-trap	239.66
Homestead icehouse	609.92
Homestead shop	262.91
Instructors' salaries	3,175.00
Interest	150.00
Lectures	25.96
Library	1,297.71
Maintenance of buildings and grounds	1,879.00
Mosquito fund	280.47
Real estate	5,100.00
Scientific instruments	504.19

[1] Owing to a change in classification of expenses, the amounts charged the various accounts are not comparable with the reports of previous years.

Sundries	219.81	
Supply department	8,008.53	$33,029.07[1]

ITEMIZED LIST OF SUNDRY EXPENSES FOR THE YEAR 1911

Expenses of W. C. Curtis	$29.79	
Howes' bills	1.84	
Teaming and freight	2.57	
Express	19.00	
Exchange on checks	21.36	
Care of lot in cemetery	2.00	
Gasoline for gas machine	31.90	
Palmer & Laughlin (order W. C. Curtis)	6.00	
S. I. Snow (sundry bills)	3.67	
Blades	.50	
U. S. Powers (sundry bills)	2.10	
Services John G. Hubbard	60.00	
Ice	11.25	
John J. Veeder	.50	
Trustees' dinner	17.00	
E. E. Swift & Son	2.57	
Carpenter	13.74	
Charles J. Grinnell	1.35	
John F. Phillips (teaming)	5.30	
Premium on bond on alcohol	7.50	
Recording deed	.89	
Recording declaration of trust	.79	
Express on pay-rolls to Woods Hole	5.25	
Pay-roll envelopes	.29	
Telegram	.30	
Tracing paper	3.60	
Carpenter (botany department)	.45	$251.51

Credit

Petty cash at Woods Hole for 1910	$ 1.00	
Reprints	5.30	
Harvard Apparatus Company (check sent by error last year)	25.40	31.70
		$219.81

[1] On January 1, 1911, the Laboratory had cash on hand $2,719.17; the overdraft for the year was therefore $56.41, which has since been adjusted.

Mosquito Fund

Receipts

1910	Miss S. B. Fay	$100.00	
	Joseph Fay, Jr.	100.00	
	A. C. Harrison	100.00	
	H. K. Dyer	100.00	
1911	Charles R. Crane	100.00	$500.00

Payments

1910	Services H. H. Brehme	$ 50.00	
	3 pair rubber boots	19.50	
	Labor (regular pay-roll)	30.00	
	Nets	1.47	
1911	Oil	5.40	
	Labor digging ditch	197.40	
	Carting	73.20	
	Spray for hose	9.72	
	Dr. Drew's expenses	11.13	
	T. E. Howes, June account	6.50	
	E. C. Brown Co.	.42	
	John F. Phillips	1.70	
	Labor (regular pay-roll)	75.00	481.44
			$18.56

MARINE BIOLOGICAL LABORATORY INVESTMENTS

JANUARY 1, 1912

Reserve Fund

Amount of fund December 1, 1899	$4,553.14	
Received from life memberships	600.00	
Income to January 1, 1912	2,292.15	
Gain from sale of securities and rights	372.38	
	7,817.67	
Paid for current expenses of Laboratory	6,000.00	$1,817.67
Reserve Fund now consists of the following:		
$3,000 Am. Tel. & Tel. Co. 4s cost	$2,921.25	
5 shs. Am. Smelting & Refining Co. Pfd. cost	732.00	
5 shs. General Electric Co.	756.25	
14 shs. United Shoe Machinery Corp. Pfd. cost	393.75	
Cash	14.42	
	4,817.67	
Part of the above stocks and bonds are held as collateral for loan of	3,000.00	$1,817.67

Library Fund

Amount of fund December 1, 1899	$ 866.15	
Income to January 1, 1912	780.47	
Gain from sale of securities and rights	96.39	$1,743.01
Library Fund now consists of the following:		
3 shs. Am. Tel. & Tel. Co. cost	$ 383.25	
4/5 of $1,000 Am. Tel. & Tel. Co. 4s cost	779.00	
1 sh. Am. Smelting & Refining Co. Pfd. cost	122.00	
2 shs. General Electric Co. cost	302.50	
5 shs. United Shoe Mach. Corp. Pfd. cost	140.63	
Cash	15.63	$1,743.01

Lucretia Crocker Fund

Amount of fund December 1, 1899	$2,500.00	
Income after paying students' fees	557.91	
Sale of rights	8.79	$3,066.70

Lucretia Crocker Fund now consists of the following:

18 shs. Vermont & Mass. R. R. Co. cost	$2,416.50	
1 sh. West End Street R'y Co. cost	83.00	
1 sh. Am. Tel. & Tel. Co. cost	127.75	
1/5 of $1,000 Am. Tel. & Tel. Co. 4s cost	194.75	
1 sh. General Electric Co.	151.25	
Cash	93.45	$3,066.70

V. THE DIRECTOR'S REPORT

To the Trustees of the Marine Biological Laboratory:

Gentlemen: The session just closed is the twenty-fourth continuous session of the Laboratory. The attendance of investigators was larger than ever before in the history of the Institution, and the total attendance the greatest since 1902 when the policy of restricting instruction was first definitely established. The principle of coöperation, placed at the foundation of the Laboratory by Professor Whitman, has never more fully justified itself; and it is a pleasure to testify to the generous spirit in which the corporation, the board of trustees, the staff and the employees of the institution have labored for its welfare. Through Mr. Crane's generosity the Laboratory has been presented with the Kidder Annex property, a lot of land situated between the botanical laboratory and the main building; and with more than three fourths of the shares of the Woods Hole Yacht Club property adjoining and continuing our frontage on the harbor. These additions practically complete the arrangements necessary for the next forward step.

We note with regret the resignation of Professor Nathaniel L. Britton from the board of trustees, presented at the summer meeting, owing to his inability to take an active share in affairs, and we extend cordial greetings to Professor R. A. Harper, of Columbia University, a newly elected member of the board, whose coöperation will greatly strengthen our work, especially on the botanical side. The board of trustees remains otherwise unchanged. There are three vacancies in the membership which it is the province of the board to fill. Steps should be taken to secure the best men to fill these vacancies.

Professor Curtis resigned as head of instruction in invertebrate zoölogy at the close of the summer, after four years of service, during which he successfully maintained the best traditions of the course. Particular importance attaches to this course as the

first to be established in the Laboratory and as lying at the foundation of the more advanced work. The directors have therefore considered the question of a successor to Professor Curtis with great care, and they are happy to be able to announce that Professor Caswell Grave, of Johns Hopkins University, has accepted the appointment as Professor Curtis' successor. We believe that no better selection could have been made. Professor Grave is given a free hand in the selection of other instructors in the course.

The attendance in 1911 taxed the resources of the Laboratory to the utmost. The number of investigators was 82 during the entire season and of students 65, a total of 147. For comparison I give the figures since 1903:

	1903	1904	1905	1906	1907	1908	1909	1910	1911
Investigators..	76	51	68	68	60	52	66	62	82
Students.....	54	51	57	41	47	48	63	64	65
Total	130	102	125	109	107	100	129	126	147

But the actual increase in the number of investigators does not tell the full story. For several years there has been a steadily growing tendency on the part of workers at the Laboratory to make Woods Hole their regular summer home and to purchase houses there. The body of workers at the Laboratory has thus become not only larger, but more constant in attendance; the increase of attendance this year is therefore to be regarded as normal, not due to exceptional causes. That the Laboratory should come to be regarded as their regular summer home and working place by so large a number of prominent naturalists must be a source of gratification to all the members of the board; while it serves at the same time to emphasize anew the need of greatly increased accommodations. Such over-crowding as existed for a considerable part of last summer is certainly undesirable and its continuance for any considerable length of time could not be anticipated with composure. Neither do we wish to restrict the policy of hospitality which has been so characteristic of the Laboratory in the past.

The proposed new building is, therefore, a necessity for working space alone. And it is equally important for two other reasons:

first, to provide for the development of a more adequate library, which will remove one of the most serious limitations of our research facilities, and second, to provide more commodious quarters for certain types of research, especially in experimental lines. For the season of 1912 some additional working space will be available in the Kidder Annex, so that it may be hoped that the crowding will be no worse next year than it was this.

During the last five years there has been a steady increase in the number of subscribing institutions, from 16 in 1907 to 25 in 1911, and on the whole there is reason to believe that the present list contains fewer subscriptions for the year only than ever before; there are, moreover, indications that the increase in number may be expected to continue for some years to come. A new form of arrangement was entered into this year with the Rockefeller Institute for Medical Research of New York City, under the terms of which the Rockefeller Institute has erected a small laboratory for the use of Professor Jacques Loeb on land of the Marine Biological Laboratory, but receives other facilities and service on precisely the same terms as other co-operating institutions. Without the additional laboratory space thus provided, it would have been necessary to refuse accommodations to a number of investigators. The director has also been notified of the endowment of a scholarship in Normal College, New York City, in memory of Else Seringhaus, formerly a student at the Marine Biological Laboratory for several years. The income of the fund of $1,000.00, to be known as the Else Seringhaus Scholarship, is to be applied to the payment of tuition fees for one student each year at the Marine Biological Laboratory or elsewhere, as may be designated by the committee of award.

Following the recommendation in the director's report for 1910, Professor Gilman A. Drew was appointed resident assistant director at the summer meeting of the Board of Trustees. This step was taken none too soon, as the burden of administration of Laboratory affairs, which has been largely carried by Professor Drew for several years, in addition to regular university work, was already much too great; the Laboratory needs such service as Professor Drew's experience and character fit him so

eminently well to render, and we can now face the growing complexities of the Laboratory with confidence and more ease.

Among additions to the equipment of the Laboratory during the year may be noted a large motor boat, a Zeiss microscope of the best and newest model and a new microtome. The mess did an unusually large business and exhibits an unexpectedly large surplus, all of which is to be turned back into improvements in its equipment and service. Among these may be mentioned a new ice-house costing $600.00 and a work-shop costing $250.00 already completed. The supply department has made its usual gain in business transacted, and it is worth noting that under Mr. Gray's management this business has increased from $5,616.54 in 1906 to $10,303.61 in 1911.

Our thanks are again due Mr. Crane for the donations which have enabled us to maintain the work of the Laboratory on an efficient basis; and for the presentation of additional stock of the Yacht Club, and the Kidder Annex property.

There are appended as parts of this report the names of the staff for 1911, a list of investigators and students with a tabular view of attendance since 1908, and lists of subscribing institutions, of the evening lectures for 1911, and of the members of the corporation.

1. THE STAFF.

F. R. LILLIE, DIRECTOR,

Professor of Embryology and Chairman of the Department of Zoölogy, The University of Chicago.

GILMAN A. DREW, ASSISTANT DIRECTOR,

Professor of Biology, University of Maine.

ZOÖLOGY

I. INVESTIGATION

Zoölogy and Embryology

GARY N. CALKINS.....Professor of Protozoölogy, Columbia University.
E. G. CONKLIN.....Professor of Zoölogy, Princeton University.
GILMAN A. DREW.....Professor of Biology, University of Maine.
GEORGE LEFEVRE.....Professor of Zoölogy, University of Missouri.
FRANK R. LILLIE.....Professor of Embryology, The University of Chicago.
T. H. MONTGOMERY, JR..Professor of Zoölogy, University of Pennsylvania.
T. H. MORGAN.....Professor of Experimental Zoölogy, Columbia University.
E. B. WILSON.....Professor of Zoölogy, Columbia University.

II. INSTRUCTION

WINTERTON C. CURTIS...Professor of Zoölogy, University of Missouri.
PAUL M. REA.....Professor of Biology, College of Charleston, and Director of the Charleston Museum.
EDWARD E. WILDMAN....Central High School, Philadelphia.
JOHN W. SCOTT.....Westport High School, Kansas City.
G. S. DODDS.....Professor of Biology, St. Louis University.
J. F. ABBOTT.....Professor of Zoölogy, Washington University.

EMBRYOLOGY

I. INVESTIGATION. (See Zoölogy)

II. INSTRUCTION

GILMAN A. DREW.....Professor of Biology, University of Maine.
LORANDE L. WOODRUFF..Assistant Professor of Biology, Yale University.
WILLIAM E. KELLICOTT..Professor of Biology, Goucher College.
ROBERT A. BUDINGTON...Associate Professor of Zoölogy, Oberlin College.

PHYSIOLOGY

I. INVESTIGATION

ALBERT P. MATHEWS....Professor of Physiological Chemistry, The University of Chicago.
R. S. LILLIE.....Instructor in Comparative Physiology, University of Pennsylvania.
HAROLD C. BRADLEY.....Assistant Professor of Physiological Chemistry, University of Wisconsin.

II. INSTRUCTION

H. H. NEWMAN.....Professor of Zoölogy, University of Texas.
CHARLES G. ROGERS.....Associate Professor of Physiology, Syracuse University.
F. H. PIKE.....Instructor in Physiology, The University of Chicago.

PHILOSOPHICAL ASPECTS OF BIOLOGY AND ALLIED SCIENCES

LECTURES

EDWARD G. SPAULDING...Assistant Professor of Philosophy, Princeton University.

BOTANY

GEORGE T. MOORE.....Professor of Plant Physiology and Applied Botany, Washington University.
GEORGE R. LYMAN.....Assistant Professor of Botany, Dartmouth College.
B. M. DUGGAR.....Professor of Plant Physiology, Cornell University.
IVEY F. LEWIS.....Professor of Biology, Randolph-Macon College.
LEWIS KNUDSON.....Instructor in Plant Physiology, Cornell University.

LIBRARY

H. McE. KNOWER.....University of Cincinnati, Librarian.

CHEMICAL SUPPLIES

OLIVER S. STRONG.....College of Physicians and Surgeons, New York City, Chemist.

G. M. GRAY.....Curator of Supply Department.
THOMAS M. DOUTHART
and JOHN J. MORTON..Collectors in Zoölogy.
J. M. IRWIN.....Collector in Botany, Dartmouth College.
JOHN VEEDER.....Cockswain.

2. INVESTIGATORS AND STUDENTS

1911

INVESTIGATORS—OCCUPYING ROOMS.

ZOÖLOGY

ABBOTT, JAMES FRANCIS, Professor of Zoölogy, Washington University.
ADDISON, W. H. F., Demonstrator of Histology and Embryology, University of Pennsylvania.
BARTELMEZ, GEORGE W., Associate in Anatomy, University of Chicago.
BECKWITH, CORA J., Instructor in Biology, Vassar College.
BUDINGTON, ROBERT A., Associate Professor of Zoölogy, Oberlin College.
CALKINS, GARY N., Professor of Protozoölogy, Columbia University.
CHAMBERS, ROBERT, Columbia University.
CLAPP, CORNELIA M., Professor of Zoölogy, Mount Holyoke College.
CONKLIN, E. G., Professor of Zoölogy, Princeton University.
CRAIG, WALLACE, Professor of Philosophy, University of Maine.
CURTIS, W. C., Professor of Zoölogy, University of Missouri.
DODDS, GIDEON S., Instructor of Zoölogy, University of Missouri.
DREW, GILMAN A., Assistant Director, Marine Biological Laboratory, Woods Hole, Mass.
DUNN, ELIZABETH HOPKINS, Instructor in Anatomy, University of Chicago.
FOX, HENRY, Professor of Biology, Ursinus College, Collegeville, Pa.
GOLDFARB, A. J., Instructor, College of the City of New York.
HARVEY, BASIL C. H., Assistant Professor of Anatomy, University of Chicago.
HARVEY, E. NEWTON, Instructor in Physiology, Princeton University.
HOGUE, MARY J., Instructor in Zoölogy, Mount Holyoke College.
KELLEY, FRANK J., Assistant in Experimental Breeding, University of Wisconsin.
KELLICOTT, WILLIAM E., Professor of Biology, Goucher College.
KNOWER, H. McE., Professor of Anatomy, University of Cincinnati.
LEFEVRE, GEORGE, Professor of Zoölogy, University of Missouri.
LILLIE, FRANK R., Professor of Embryology, University of Chicago.
LYON, MARY B., Instructor in Zoölogy, Mount Holyoke College.
MCCLUNG, C. E., Professor of Zoölogy, University of Kansas.
MAYER, A. G., Director, Department of Marine Biology, Carnegie Institution.
MONTGOMERY, T. H., Jr., Professor of Zoölogy, University of Pennsylvania.
MORGAN, T. H., Professor of Experimental Zoölogy, Columbia University.
PACKARD, CHARLES, Assistant in Zoölogy, Columbia University.
PATON, STEWART, Lecturer in Biology, Princeton University.
PATTEN, WILLIAM, Professor of Biology, Dartmouth College.
PATTERSON, J. T., Adjunct Professor of Zoölogy, University of Texas.
QUACKENBUSH, L. S., 27 West 73d Street, New York City.
REA, PAUL M., Professor of Biology, College of Charleston.
SCOTT, JOHN W., Westport High School, Kansas City, Mo.

STRONG, OLIVER S., Instructor in Anatomy, College of Physicians and Surgeons, New York City.
WHITNEY, D. D., Associate Professor of Zoölogy, Wesleyan University, Middletown, Conn.
WIEMAN, H. L., Assistant Professor of Zoölogy, University of Cincinnati.
WILDMAN, E. E., Professor of Zoölogy, Central High School, Philadelphia, Pa.
WILSON, E. B., Professor of Zoölogy, Columbia University.
WOODRUFF, L. L., Assistant Professor of Biology, Yale University.

PHYSIOLOGY

AMBERG, SAMUEL, Associate Professor of Pediatrics, Johns Hopkins University.
BANCROFT, FRANK W., Associate, Rockefeller Institute for Medical Research, New York City.
BEUTNER, REINHARD, Assistant, Rockefeller Institute for Medical Research, New York City.
BRADLEY, H. C., Assistant Professor of Physiological Chemistry, University of Wisconsin.
DONALDSON, H. H., Professor of Neurology, Wistar Institute of Anatomy and Biology.
FERGUSON, J. S., Assistant Professor of Histology, Cornell University Medical School.
GLASER, O. C., Assistant Professor of Zoölogy, University of Michigan.
LILLIE, R. S., Instructor in Physiological Zoölogy, University of Pennsylvania.
LOEB, JACQUES, Rockefeller Institute for Medical Research, New York City.
MATHEWS, A. P., Professor of Physiological Chemistry, University of Chicago.
MATHEWS, SAMUEL A., Assistant Professor of Experimental Therapeutics, University of Chicago.
MEIGS, E. B., Fellow in Zoölogy, Wistar Institute of Anatomy and Biology.
NEWMAN, H. H., Associate Professor of Zoölogy, University of Chicago.
PIKE, FRANK W., Instructor in Physiology, University of Chicago.
ROGERS, CHARLES G., Professor of Physiology, Syracuse University.
SPAULDING, E. G., Assistant Professor of Philosophy, Princeton University.
WASTENEYS, HARDOLPH, Assistant, Rockefeller Institute for Medical Research, New York City.

BOTANY

DERICK, CARRIE M., Assistant Professor of Botany, McGill University.
DUGGAR, B. M., Professor of Plant Physiology, Cornell University.
KNUDSON, LEWIS, Instructor in Plant Physiology, Cornell University.
LEWIS, IVEY F., Professor of Biology, Randolph-Macon College.
LYMAN, GEORGE R., Assistant Professor of Botany, Dartmouth College.
MOORE, GEORGE T., Professor of Botany, Washington University, St. Louis, Mo.
OSTERHOUT, W. J. V., Assistant Professor of Botany, Harvard University.
THOMAS, MASON B., Professor of Botany, Wabash College.

OCCUPYING TABLES

ZOÖLOGY

ABBOTT, MARGARET B., Bennett School, Millbrook, New York.
ALLYN, HARRIET M., Fellow in Zoölogy, University of Chicago.
BROWNE, ETHEL N., Graduate Student, Columbia University.

DAVIS, SARAH ELLEN, 512 West 132d Street, New York City.
DUNGAY, NEIL S., Professor of Biology, Carleton College, Northfield, Minn.
EDDY, MILTON W., Northwestern University, Evanston, Ill.,
ENNIS, AGNES, 453 Convent Avenue, New York City.
JUST, E. E., Instructor in Biology, Howard University.
MACKENZIE, MARY D., Associate Professor of Biology, Western College, Oxford, Ohio.
SPENCER, HENRY J., Graduate Student, Columbia University.
SINK, EMORY W., Assistant in Zoölogy, University of Michigan.
WALLACE, EDITH M., Columbia University.

PHYSIOLOGY

MORSE, MAX W., Professor of Biology, Trinity College, Hartford, Conn.
TASHIRO, SHIRO, Student, University of Chicago.

STUDENTS

1911

INVERTEBRATE ZOÖLOGY

BAIRD, GRACE J., 608 Mathews Avenue, Urbana, Ill.
BOLAND, MILDRED, Western College, Oxford, Ohio.
BROWN, VIRGINIA R., 341 Prescott Street, Toledo, Ohio.
BUTTERWECK, JOSEPH R., 1729 Turner Street, Allentown, Pa.
COPENHAVER, NAT H., Bristol, Tenn.
DEXTER, JOHN S., Professor of Biological Sciences, Northland College, Ashland, Wisconsin.
DODD, HELEN N., 25 Appleton Place, Glen Ridge, N. J.
DODD, JENNIE S., 333 West 77th Street, New York City.
FERGUSON, ALBERT B., University of Maine, Orono, Maine.
FLANIGEN, RUTH, William Penn High School, Philadelphia.
GIBBS, ETHEL C., Carthage, New York.
JENNER, EDWIN A., Professor of Biology, Simpson College, Indianola, Iowa.
JOHNSON, BERTHA T., Oberlin College, Oberlin, Ohio.
LYNCH, FRANCES M., Goucher College, Baltimore, Md.
NUTE, HELEN E., 914 Highland Avenue, Fall River, Mass.
MURRAY, MARJORIE F., Bryn Mawr College.
ROWE, ELIZABETH A., 1835 E. Baltimore Street, Baltimore, Md.
SCHIEL, DORA E., Mount Holyoke College.
SMILEY, CAROLYN D., Mount Holyoke College.
SNYDER, HELEN C., 42 Madison Avenue, Jersey City, N. J.
SPRAY, RUTH G., University of Kansas.
STEFFEN, ANNA E., Oberlin College.
TRENOR, ALBERT D., 142 E. 62d Street, New York City.
WARREN, HELEN F., 16 Brent Street, Dorchester, Mass.
WHITE, ESTHER L., Meridian College, Meridian, Texas.

EMBRYOLOGY

ALTENBURG, EDGAR, 2803 Third Avenue, New York City.
ANDEREGG, LOUIS T., Oberlin College.
BOX, CORA M., Instructor, University of Cincinnati.
BURKE, EDMUND J., Instructor in Biology, Holy Cross College, Worcester, Mass.
CATTELL, MCKEEN, Garrison, New York.
COLLETT, MARY E., 915 North 5th Street, Atchinson, Kansas.
COOPER, GEORGIA M., 13 Highland Avenue, Auburn, Maine.
GLASCOCK, HARDIN R., Ohio Wesleyan University, Delaware, Ohio.
GLASER, RUDOLPH W., University of Michigan.
HOGE, MILDRED A., Western High School, Baltimore, Md.
KELLY, JAMES P., Black Rock Avenue, Unionport, New York City.
MORRISS, MARGARET, 53 Edgehill Road, New Haven, Conn.

MULLER, HERMANN J., 562 West 150th Street, New York City.
PAINTER, THEOPHILUS S., Yale University.
PATTEN, HAZEL, 1719 McCulloh Street, Baltimore, Md.
RICHARDS, ETHEL L., Washington University, St. Louis, Mo.
SAENZ, MOISES, Washington and Jefferson College, Washington, Pa.
SCHWITALLA, ALPHONSE M., Instructor in Biology, St. Louis University.
WHEELER, THEODORA, Fairfield, Conn.
WALKER, GEORGE, Associate in Surgery, Johns Hopkins University.
NORTHRUP, JOHN H., 500 Washington Avenue, Yonkers, New York.

PHYSIOLOGY

BIGNEY, ANDREW J., Professor of Biology and Geology, Moores Hill College, Indiana.
CARROLL, ALBERT H., "Evergreen," Hampden, Baltimore, Md.
ICKES, MARGARET, Smith College, Northampton, Mass.
KELLERSBERGER, EUGENE R., University of Texas.
NORCROSS, KATHARINE, University of Chicago.
OLIVER, WADE W., University of Michigan.

BOTANY

BOSSON, RICHARD M., Wabash College.
CAREY, CORNELIA L., Box 956, Orange, N. J.
CURTIS, OTIS F., 163 North Main Street, Oberlin, Ohio.
DAWSON, AVA B., 97 Mountfort Street, Boston, Mass.
FAUST, ERNEST C., Oberlin College.
GROSS, BEATRIX H., Normal College, New York City.
HILL, ALBERT F., 192 South Main Street, Attleboro, Mass.
JENNISON, HARRY M., Auburn, Mass.
KENOYER, LESLIE A., Leander Clark College, Toledo, Iowa.
NOBLE, ARLYLE, Smith College.
RICHARDS, ANNABELLA E., Ventnoe City, N. J.
WELSH, CARLTON K., Dartmouth College.
PENNELL, FRANCIS W., Harrison Fellow in Botany, University of Pennsylvania.

3. TABULAR VIEW OF ATTENDANCE

	1908	1909	1910	1911
INVESTIGATORS—Total	52	66	62	82
Occupying Rooms				
Zoölogy	32	39	33	42
Physiology	6	7	9	18
Botany	8	4	9	8
Occupying Tables				
Zoölogy	6	14	5	12
Physiology		2	2	2
Botany			1	
STUDENTS—Total	48	63	64	65
Zoölogy	19	36	31	26
Embryology	15	12	10	20
Physiology	3	9	5	6
Botany	11	6	17	13
INSTITUTIONS REPRESENTED				
By Investigators	25	27	26	37
By students	26	20	24	31
SCHOOLS AND ACADEMIES REPRESENTED				
By investigators	2	3	5	3
By students	3	11	6	9

4. SUBSCRIBING INSTITUTIONS, 1911

Bryn Mawr College.
Columbia University.
Dartmouth College.
Goucher College.
Lucretia Crocker Scholarship.
Mount Holyoke College.
Northwestern University.
Oberlin College.
Princeton University.
Rockefeller Institute for Medical Research.
Sheffield Scientific School of Yale University.
Smith College.
Syracuse University.
Trinity College, Hartford, Conn.
University of Chicago.
University of Cincinnati.
University of Illinois.
University of Kansas.
University of Michigan.
University of Pennsylvania.
Vassar College.
Washington University Alumni Association.
Western College for Women.
Wellesley College.
Wistar Institute of Anatomy and Biology.
Scholarship of $100. Supported by a friend of the Laboratory since 1898.

5. EVENING LECTURES, 1911

GARY N. CALKINS....."The Scope of Protozoölogy"....June 30.
G. H. PARKER....."Some Recent Work on Animal Reactions to Colored Light"..July 3.
T. H. MORGAN....."What is the Mechanism of Mendelian Segregation in the Germ Cells?".....July 7.
I. F. LEWIS....."Alternation of Generations and Periodicity in the Marine Algæ"July 11.
SIMON FLEXNER....."The Biological Basis of the Treatment of Disease".....July 14
WALLACE CRAIG....."Why Do Birds Sing?".....July 18.
J. MCKEEN CATTELL...."Science and Democracy".....July 21.
BRADLEY M. DAVIS....."The Synthesis and Behavior of Some Hybrids that Resemble *Œnothera Lamarckiana*".....July 25.
JACQUES LOEB....."The Life-Preserving Action of Salts".....July 28.
E. G. SPAULDING....."Bergson's Creative Evolution"..Aug. 4.
W. M. WHEELER....."Insect Parasitism and Its Peculiarities".....Aug. 8.

6. MEMBERS OF THE CORPORATION OF THE MARINE BIOLOGICAL LABORATORY AUGUST 8, 1911

Life Members

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Billings, Mr. R. C., 66 Franklin Street, Boston, Mass.

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Conklin, Dr. E. G., Princeton University, Princeton, New Jersey.

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Foot, Miss Katharine, 80 Madison Avenue, New York City.

Gardiner, Miss Eugenia, 15 West Cedar Street, Boston, Mass.

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Hannaman, Mr. Charles E., 103 First Street, Troy, New York.

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Jackson, Mr. Charles C., 24 Congress Street, Boston, Mass.

Kennedy, Mr. George G., 284 Warren Street, Roxbury, Mass.

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Kidder, Mr. Nathaniel T., Milton, Mass.

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WILSON, PROF. W. P., Philadelphia Museum, Philadelphia, Pa.

MEMBERS OF THE CORPORATION OF THE MARINE BIOLOGICAL LABORATORY,

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[1] Deceased.